

“Microbial Paleontology, Mineralogy and Geochemistry of Modern and Ancient Thermal Spring Deposits and Their Recognition on the Early Earth and Mars”

Final Progress Report

Jack D. Farmer, Principal Investigator
Arizona State University
Department of Geological Sciences
PO Box 871404
Tempe, AZ 85287-1404

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The vision of this project was to improve our understanding of the processes by which microbiological information is captured and preserved in rapidly mineralizing sedimentary environments. Specifically, the research focused on the ways in which microbial mats and biofilms influence the sedimentology, geochemistry and paleontology of modern hydrothermal spring deposits in Yellowstone national Park and their ancient analogs. Toward that goal, we sought to understand how the preservation of fossil biosignatures is affected by 1) taphonomy- the natural degradation processes that affect an organism from the time of its death, until its discovery as a fossil and 2) diagenesis- longer-term, post-depositional processes, including cementation and matrix recrystallization, which collectively affect the mineral matrix that contains fossil biosignature information. Early objectives of this project included the development of observational frameworks (facies models) and methods (highly-integrated, interdisciplinary approaches) that could be used to explore for hydrothermal deposits in ancient terranes on Earth, and eventually on Mars.

As mentioned, studies of modern hydrothermal systems focused on alkaline, low salinity hot springs in Yellowstone Park, representing a broad range of sinter compositions (siliceous, carbonate and iron-oxide). The grant was awarded in 1999, but the PI moved to a new institution and the start date was delayed by the NASA Exobiology program until 2001, while new lab facilities were being constructed. Specific studies accomplished during the grant period include:

- Studies of travertine springs at Angel Terrace, Mammoth Hot Springs, Yellowstone National Park (YNP), with post-doc Bruce Fouke (presently a tenured Professor at the University of Illinois and presently funded for molecular studies of the same environments; see Farmer 2000; Fouke et al. 2000)
- Studies of iron-depositing hot-springs (Chocolate Pots, Norris Geyser Basin, YNP) with Ph.D. student, Manson Wade and Profs. David Agresti and Tom Wdowiak, (University of Alabama; see Wade et al. 1999).
- Siliceous thermal springs of Yellowstone (with post-doc Sherry Cady, now a tenured Professor at Portland State University and Editor of the journal,

Astrobiology; see Cady et al. 2003) and with Brad Bebout (Research Scientist, NASA Ames) to define facies frameworks for modern siliceous springs in Yellowstone and to use mounted microelectrodes to determine pH and oxygen microprofiles within sinter frameworks. The latter showed (in preparation for publication) showed that sinters retain high concentrations of photosynthetic oxygen within exopolymer matrixes, that acts to drive intense biomediated oxidation of organic matter entrapped within sinter frameworks.

Observations of modern springs were applied to interpretations of a variety of ancient analog deposits, including:

- Devonian-aged sinters of NE Queensland, Australia (with Malcolm Walter, Macquarie Univ., Sydney. Director of the Australian Astrobiology Institute); Jurassic-aged methane seep carbonates of the central California Coast Range, with post-doc Kathleen Campbell (see Campbell, Farmer and Des Marais, 2002). Dr. Campbell is presently a tenured Professor at the University of Auckland and heads the Auckland Sinter project, which coordinates and conducts studies of New Zealand hot springs.
- Subsurface hydrothermal deposits in Iceland and the southern Mojave Desert (with Dr. Beda Hofmann, Curator of Mineralogy, Museum of Natural History, Bern Switzerland (see Hofmann and Farmer. 2000), as well as continuing studies with ASU Ph.D. candidate, Ms. Susan Schulz (planned graduation, 08/2007).
- Pleistocene-aged, subsurface, subaerial and lake floor travertines in Death Valley (studies by ASU Masters candidate, Ms. Tomoko Adachi; graduated 08/2005).

These published studies (see list of peer reviewed publications below), represent a wide range of modern and ancient hydrothermal systems, and have provided important new insights into the nature of microbial biosignature preservation in alkaline hydrothermal systems, over a broad range of temperature and geochemical spring compositions. Experience gained through these studies has been influential in developing strategies for the astrobiological exploration of Mars, while serving as a backdrop for the PI's contributions to several NASA programmatic efforts aimed at refining a long-term strategy for Mars exploration over the next decade and beyond (Mars Exploration Program Advisory Group's strategy for Mars Exploration; NASA Solar System Exploration Subcommittee strategic planning efforts; Science Definition teams for the Mars Reconnaissance Orbiter mission (just launched, 08-2005) and the Mars Science Laboratory (MSL) mission (to be launched in 2009). These studies also influenced site selection for the Mars Exploration Rover mission (for which the PI is also a Participating Scientist) and produced several papers outlining strategies for Mars exopaleontology (e.g. see Farmer 2000; Farmer 1999a,b; Farmer and Des Marais 1999).

In addition to the successful graduate training efforts and scientific collaborations identified above, during the grant period, the lead PI presented numerous public talks on the topic of Mars exopaleontology, while contributing to the following E&PO products:

Television Interviews and Documentaries:

- NHK Japan special on the Mars Exploration Rover mission. Filmed segments at field sites in Yellowstone and Mono Basin (2004).
- Discovery Daily Science, Canada. Live interviews, "Water on Mars" (June 2000; Jan. 2001).
- PBS "Cosmic Safari". Invincible Films, London on exploring for extraterrestrial life (Feb. 2000).
- CNN Interview: "Yellowstone hot-springs, biotechnology and Mars exploration". Topics: The exploration for novel microbial enzymes in Yellowstone hot-springs, studies to better understand the early biosphere evolution and to explore for life on Mars or Europa (March 1998).

Education (Teacher Training Activities):

- Guest Scientist, Jason Foundation for Education (2004-05). Jason Expedition: "Mysteries of Earth and Mars". Provided content and review of materials for a K-12 science curriculum, lead a summer field expedition for teachers to northern Arizona (Grand Canyon, San Francisco Mts. and Meteor Crater) and presented keynote lecture to Jason students and teachers at a Jason—sponsored meeting in Ohio.
- With the SETI Institute, the PI developed educational materials about the origins of life for a CD ROM-based high school curriculum in Astrobiology (2002).
- In 2002, the PI prepared a field guidebook and lead a field trip for 30 teachers to the Mono Basin to explore analog connections for Mars exploration. Sponsored by the ASU-NASA Mars Thermal Emission Spectrometer K-12 outreach effort.

Public and Professional Outreach:

- In 2002-2005, the PI Worked with NASA Astrobiology Institute/Yellowstone National Park to 1) develop "thermophiles and Mars" content for guidebook used to train the YNP interpretive staff (also published for sale to Public by YNP), 2) identify sites within YSN Park and developed content for new interpretive trail signs and 3) provide preliminary scientific content and illustrations for a new Old Faithful Visitor Center.
- In 2004, I co-organized the NASA-sponsored "Early Mars Conference" held in Jackson Hole, WY. Helped plan scientific program for Astrobiology, prepared a fieldtrip guidebook and lead field trip to hydrothermal study sites in Yellowstone National Park for ~130 meeting participants.

Peer-reviewed Publications:

Farmer, J. D. 2000. Hydrothermal Systems: Doorways to Early Biosphere Evolution, *GSA Today* 10(7), 1-9

Farmer, J.D. 2000, Exploring for a fossil record of extraterrestrial life, p. 10-15 In Derek Briggs and P. Crowther (eds.) *Palaeobiology II*, Blackwell Science Publishers, Oxford.

Farmer J. D. and D. J. Des Marais, 1999, Exploring for a record of ancient Martian life. *Journ. Geophys. Res.* 104 (E11) 26,977-26,995.

Cady, S.L., **J.D Farmer**, J.P. Grotzinger, J.W. Schopf, and A. Steele. 2003. Morphological biosignatures, *Astrobiology* 3(2): 351-368.

Campbell, K.A., **J.D. Farmer** and D. Des Marais, 2002, Ancient hydrocarbon seeps from the Mesozoic convergent margin of California: carbonate geochemistry, fluids and paleoenvironments, *Geofluids* 2: 63-94.

Farmer, J.D. 1999a. Taphonomic modes in microbial fossilization. pp. 94-102, In *Proceedings of the Workshop on Size Limits of Very Small Microorganisms*. Space Studies Board, National Research Council, National Academy Press, Washington D.C.

Farmer, J.D. 1999b. Implementing a strategy to explore for ancient Martian life, p. 58-65, In Julian Hiscox (Editor) *The Search for Life on Mars*, Special Issue, British Interplanetary Society, London.

Farmer, J.D. 1998. Thermophiles, early biosphere evolution and the origin of life on Earth: Implications for the exobiological exploration of Mars. *Journal of Geophysical Research* 103: 28,457-28,461.

Fouke, B.W., **J.D. Farmer**, D.J. Des Marais, L. Pratt, N.C. Sturcio, P.C. Burns, and M.K. Discipulo 2000, Depositional facies and aqueous-solid geochemistry of travertine-depositing hot-springs (Angel Terrace, Mammoth Hot-springs, Yellowstone National Park, U.S.A.), *Journ. Sed. Res.* 70(3), 565-585.

Hofmann, B.A. and **J.D. Farmer**. 2000. Filamentous fabrics in low-temperature mineral assemblages: are they fossil biomarkers? Implications for the search for a subsurface fossil record on the early Earth and Mars. *Planet. Space Sci.*, 48: 1077-1086.

Janhke, L.L., T. Embaye, J. Hope, K. A. Turk, M. Van Zuilen, D. J. Des Marais, **J. D. Farmer** and R. E. Summons. 2004. Lipid biomarker and carbon isotopic signatures for stromatolite-forming, microbial mat communities and *Phormidium* cultures from Yellowstone National Park, *Geobiology* 2: 31-47.

Wade, M.L., D.G. Agresti, T.J. Wdowiak, L.P. Armendarez, and **J.D. Farmer**. 1999, A Mossbauer investigation of iron-rich terrestrial hydrothermal vent systems: Lessons for Mars exploration, *Journ. Geophys. Res.* 104 (E4), 8489-8507.

Walter, M.R., S. McLoughlin, A.N. Drinnan, and **J.D. Farmer**. 1998. Palaeontology of Devonian thermal spring deposits, Drummond Basin, Australia. *Alcheringa* 22, 285-314.

Papers in preparation, or submitted and in review:

Farmer, J.D. and B. Bebout. Role of photosynthetic oxygen in the microbial taphonomy of alkaline hot-spring sinters. *Geology* (in preparation)

Farmer, J.D. Microbial biosignature preservation in mixed silica-iron oxide springs, Chocolate Pots, Norris Geyser Basin, Yellowstone National Park. *Geobiology* (in preparation)

Adachi, T. and **J. D. Farmer**. 2005. Plio-Pleistocene hydrothermal deposits of the Furnace Creek area, Death Valley (CA). *Geobiology* (in preparation).

Farmer, J.D. 2005. An integrated litho- a biofacies model for travertine hydrothermal springs, Mammoth Hot Springs, Yellowstone National Park (WY). *Geobiology* (in preparation).